METHOD FOR FABRICATING SEMICONDUCTOR DEVICE

BACKGROUND OF THE INVENTION

The present invention relates to a method for fabricating a semiconductor device that can prevent resist collapse from being caused by resist patterning in a dry etching process.

A known method for fabricating a semiconductor device will be described with reference to the drawings.

Figures **3A** through **3D** show the cross-sectional structures of a semiconductor device in the order corresponding to process steps of the known method for fabricating the same.

First, as shown in Figure **3A**, a thermal oxide film **102** is formed in the upper part of a semiconductor substrate **101** made of silicon. Subsequently, the top of the formed thermal oxide film **102** is coated with a resist film. Thereafter, the resist film is patterned using a lithography method, thereby forming a resist pattern **103**.

Next, as shown in Figure **3B**, dry etching is performed on the thermal oxide film **102** by using the resist pattern **103** as a mask. For example, when capacitively coupled plasma etching equipment is employed, etching conditions are as follows: tetrafluorocarbon (CF_4) is supplied at a flow rate of 50ml/min; trifluoromethyl (CHF_3) is supplied at a flow rate of 30ml/min; oxygen (O_2) is supplied at a flow rate of 5ml/min; the gas pressure is 5Pa; the upper discharge power is 1000W; and the lower discharge power is 1500W. Here, the flow rate of each gas is the one in a standard state, i.e., under 0°C and 1atm.

In recent years, the processing precision of semiconductor devices has become finer, and thus smaller pattern sizes have also been required for resist patterns **103** used as masks for patterning a film to be etched. Therefore, the physical strength of the resist patterns **103** has become smaller (see, for example, International Publication Number WO98/32162 pamphlet).

In addition, even when a semiconductor device becomes finer, the thickness of a film to be etched hardly changes. This disables the thickness of a resist pattern **103** to become smaller, because it is necessary that the selectivity to the resist at dry etching is ensured. Thus, the value of the aspect ratio (the height to the line width) of the resist pattern **103** at pattern formation has been larger.

On the other hand, a dry etching process allows the resist pattern **103** to be etched not only in the vertical direction but also in the parallel direction with respect to the principal surface of the semiconductor substrate **101**. This results in the line width of the resist pattern **103** becoming smaller during etching. Furthermore, an influence of heat and ultraviolet radiation coming from plasma used for dry etching causes stresses associated with heat stresses and degradation in the resist pattern **103**. Consequently, as the processing precision becomes finer, the upper part of the resist pattern **103** collapses from the insufficient strength of the resist pattern **103** as shown in Figure **3B**, i.e., a so-called resist collapse **103a** occurs. The resist pattern **103** in which the resist collapse **103a** occurs serves as an etching mask as it is, so that a part of the thermal oxide film **102** below the resist collapse **103a** is prevented from being etched. Consequently, a pattern abnormality **102a** is formed in the thermal oxide film **102** as shown in Figure **3C**.

Therefore, as shown in Figure **3D**, even when the resist pattern **103** is removed by performing ashing and cleaning processes, the pattern abnormality **102a** remains in the thermal oxide film **102** as it is.

As described above, the known method for fabricating a semiconductor device has the problem that a resist collapse **103a** occurs in a resist pattern **103** at the etching of a film to be processed.

SUMMARY OF THE INVENTION

The present invention is made to solve the above problem, and therefore an object of the present invention is to realize a fine pattern without causing resist collapse.

After various studies, the present inventors found that a patterned resist pattern exposed to a gas containing sulfur increases the strength of each of the sidewalls of the resist pattern.

To be specific, a resist pattern made of a commonly used organic material such as novolac and containing carbon was exposed to a gas made of, for example, sulfur dioxide, and the resultant resist pattern was measured by Auger Electron Spectroscopy (AES). Consequently, sulfur atoms were identified in each of the sidewalls of the resist pattern. Furthermore, it has been shown by X-ray Photoelectron Spectroscopy (XPS) that bonds between carbon (C) and sulfur (S) (hereinafter, referred to as C-S bonds) exist in each of the sidewalls. A compound containing C-S bonds has a relatively low vapor pressure, and therefore it remains in each of the sidewalls of the resist pattern without being eliminated therefrom. In addition, the energy of the C-S bond is 175kcal/mol, which is larger than the value of the energy of the bond between carbon and carbon (C-C bond), that is, 144kcal/mol, so as to increase the strength of each of the sidewalls of the resist pattern. As a result, the resist collapse can be prevented.

More specifically, a method for fabricating a semiconductor device according to the present invention comprises the steps of: forming a thin film made of an inorganic material; forming a resist film containing carbon on the thin film and thereafter patterning the formed resist film to form a resist pattern from the resist film; exposing the resist pattern to a gas containing sulfur; and performing dry etching of the thin film using as a mask the resist pattern exposed to the gas containing sulfur.

According to the method for fabricating a semiconductor device of the present invention, a compound containing C-S bonds is generated on each of the sidewalls of the resist pattern as described above. Therefore, the strength of each of the sidewalls of the resist pattern is increased. As a result, a resist collapse can be prevented from being caused in a fine resist pattern, thereby obtaining a desired fine pattern of the thin film made of an inorganic material.

A sulfur dioxide gas described in International Publication Number WO98/32162 pamphlet is employed for etching a thin film made of an organic material, and therefore this is different from the case of the present invention where the target to be etched is made of an inorganic material.

In the method for fabricating a semiconductor device of the present invention, it is preferable that the inorganic material contains silicon and an etching gas employed for the dry etching is a fluorocarbon gas.

In the method for fabricating a semiconductor device of the present invention, the gas containing sulfur is preferably sulfur dioxide.

In the method for fabricating a semiconductor device of the present invention, the gas containing sulfur is preferably in a plasma state.

In the method for fabricating a semiconductor device of the present invention, the step of exposing the resist pattern to the gas containing sulfur and the step of performing dry etching preferably constitute the same step. This eliminates the need for providing a process step for only exposing the resist pattern to the gas containing sulfur, thereby improving the throughput of the fabricating process.

In the method for fabricating a semiconductor device of the present invention, the line width of the resist pattern is preferably 200nm or less.

In the method for fabricating a semiconductor device of the present invention, the value of the ratio of the height of the resist pattern to the line width thereof is preferably 2.8 or more.

In this way, when the resist pattern is fine and has a high aspect ratio, the effects of the present invention become more noticeable.

BRIEF DESCRIPTION OF THE DRAWINGS

Figures **1A** through **1D** are structural cross sectional views showing a method for fabricating a semiconductor device according to a first embodiment of the present

invention in the order corresponding to process steps of the same method.

Figures **2A** through **2C** are structural cross sectional views showing a method for fabricating a semiconductor device according to a second embodiment of the present invention in the order corresponding to process steps of the same method.

Figures **3A** through **3D** are structural cross sectional views showing a known method for fabricating a semiconductor device in the order corresponding to process steps of the same method.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

(Embodiment 1)

A first embodiment of the present invention will be described hereinafter with reference to the drawings.

Figures **1A** through **1D** show the cross-sectional structures of a semiconductor device in the order corresponding to process steps of the method for fabricating the same according to a first embodiment of the present invention.

First, as shown in Figure **1A**, a silicon oxide film **2** made of an inorganic material is formed in the upper part of a semiconductor substrate **1** made of silicon (Si), for example, by a thermal oxidation method. Subsequently, the top of the formed silicon oxide film **2** is coated with a resist film. Thereafter, the resist film is patterned using a lithography method, thereby forming a resist pattern **3**.

Next, as shown in Figure **1B**, the resist pattern located on the semiconductor substrate **1** is exposed to plasma-like sulfur dioxide (SO_2), thereby forming a C-S reaction part **3a** containing C-S bonds on each of the sidewalls of the resist pattern **3**. More specifically, plasma is generated, for example, using inductively coupled plasma etching equipment, wherein the flow rate of sulfur dioxide is 50ml/min (0°C, 1atm), the gas pressure is 1Pa, the upper discharge power is 200W, and the lower discharge power is 30W. This plasma irradiation allows sulfur dioxide to be decomposed into sulfur (to be formed in

plasma) and then allows the generated sulfur atoms to bond to carbon atoms contained in the resist pattern **3**, thereby forming a C-S reaction part **3a** on each of the sidewalls of the resist pattern **3**. The formed C-S reaction part **3a** protects each of the sidewalls of the resist pattern **3** and also improves the strength of the resist pattern **3**. At this time, the silicon oxide film **2** hardly reacts with sulfur. Therefore, sulfur is not adhered to the surface of the silicon oxide film **2** so that the next process step for performing dry etching of the silicon oxide film **2** is not affected.

Next, as shown in Figure **1C**, the silicon oxide film **2** is etched using a fluorocarbon gas as an etching gas and the resist pattern **3** as a mask. For example, tetrafluorocarbon (CF_4) and trifluoromethyl (CHF_3) are employed as a fluorocarbon gas. At this time, since each of the sidewalls of the resist pattern **3** is protected by the C-S reaction part **3a**, etching can be performed without causing the resist pattern **3** to collapse.

Next, as shown in Figure **1D**, the resist pattern **3** is removed through ashing and cleaning processes.

Thereafter, the semiconductor device is completed in the usual manner.

In this way, according to the first embodiment, the formed resist pattern **3** is exposed to the gas containing sulfur, resulting in each of the sidewalls of the resist pattern **3** being protected by the C-S reaction part **3a** and being improved in strength. Therefore, the resist collapse can be prevented from being caused in the resist pattern **3**, thereby obtaining a desired shape of the silicon oxide film **2**.

(Embodiment 2)

Figures **2A** through **2C** show the cross-sectional structures of a semiconductor device in the order corresponding to process steps of a method for fabricating the same according to a second embodiment of the present invention.

First, as shown in Figure **2A**, a silicon oxide film **2** made of an inorganic material is formed in the upper part of a semiconductor substrate **1** made of silicon, for example, by a thermal oxidation method. Subsequently, the top of the formed silicon oxide film **2** is

coated with a resist film. Thereafter, the resist film is patterned using a lithography method, thereby forming a resist pattern **3**.

Next, as shown in Figure **2B**, the silicon oxide film **2** is etched by using a fluorocarbon gas as an etching gas with a sulfur dioxide gas being supplied and by using the resist pattern **3** as a mask. More specifically, capacitively coupled plasma etching equipment is employed, wherein the flow rate of tetrafluorocarbon (CF_4) is 50ml/min, the flow rate of trifluoromethyl (CHF_3) is 30ml/min, the flow rate of a carrier gas made of argon is 500ml/min, the flow rate of sulfur dioxide is 30ml/min, the whole gas pressure is 5Pa, the upper discharge power is 1000W, and the lower discharge power is 1500W. Here, the flow rate of each gas is the one in a standard state, i.e., under 0°C and 1atm.

This etching process allows sulfur dioxide added to the etching gas to generate plasma and to be decomposed, and sulfur atoms produced by this decomposition are bonded to carbon atoms contained in the resist pattern **3**, thereby forming a C-S reaction part **3a** on each of the sidewalls of the resist pattern **3**. The formed C-S reaction part **3a** protects each of the sidewalls of the resist pattern **3** and also improves the strength of the resist pattern **3**. At this time, sulfur hardly reacts with the silicon oxide film **2**. Therefore, sulfur does not affect the etching of the silicon oxide film **2**.

Next, as shown in Figure **2C**, the resist pattern **3** is removed through ashing and cleaning processes.

Thereafter, a semiconductor device is completed in the usual manner.

In this way, according to the second embodiment, when dry etching is performed on the silicon oxide film **2** by using the formed resist pattern **3** as a mask, the gas containing sulfur is added to the etching gas. Therefore, each of the sidewalls of the resist pattern **3** can be protected by the C-S reaction part **3a** and improved in strength. As a result, resist collapse can be prevented from being caused in the resist pattern **3**, thereby obtaining a desired shape of the silicon oxide film **2**.

Furthermore, the need for providing a process step of only exposing the resist pattern

3 to the gas containing sulfur is eliminated, resulting in improved throughput of the fabricating process.

In the first and second embodiments, the silicon oxide film **2** is employed as a film to be etched. However, even if another silicon oxide film such as TEOS (tetra-ethyl-ortho-silicate) or BPSG (boron-doped phospho-silicate glass), a silicon nitride film, a silicon oxynitride film, polysilicon, or amorphous silicon is employed as a film to be etched, the same effects can be obtained.

This method is also effective in etching metal interconnect made of copper (Cu) or aluminium (Al).

Although tetrafluorocarbon and trifluoromethyl are employed as the etching gas, other etching gases may be employed.

Although sulfur dioxide is employed as the gas containing sulfur, sulfur monoxide (SO) may be employed.

It is preferable that the line width of the resist pattern **3** is 200nm or less and the value of the ratio of the height of the resist pattern **3** to the line width thereof (aspect ratio) is 2.8 or more. In this way, when the resist pattern is fine and has a high aspect ratio, the effects of the present invention become more noticeable.